PHYSICS

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In the upbuilding of all the great and diverse departments of thought, characteristic methods have arisen which the human reason has found best suited to the pursuit of the many phases of truth which it seeks. In the perfection of methods and resourcefulness in applying them, no age has been more fertile than our own. Yet one ever present danger to the orderly and symmetrical development of modern thought, is that those working in different fields for its advancement may lose touch with one another, and the interchange of methods and results so essential to balanced growth, be neglected.

If in such a course of lectures as this, each lecturer coming from a neighboring or distant field succeeds in showing the nature of the evidence he has been taught to consider, his methods of weighing it and some of his results, the university will be the gainer in increased knowledge, in broadened sympathies and in a deeper realization of the wholeness of truth.

It is doubtful if our understanding of the unity of external nature can ever be illuminated by the lamp of any one of the natural sciences. The division of nature into separate departments of study has been an intellectual necessity caused by the greatness of the task.

The easiest cleavage would separate the animate from the inanimate, the biological from the physical sciences. This cleft, the first to form, will be the last to close; for to

define the precise relations of life to matter is now one of the most intricate and difficult problems in the whole range of human endeavor. Who will fundamentally answer the question, how does a seed become a tree?

The phenomena of inanimate matter are involved and complicated in the extreme, but those of living matter are even harder to understand. The outward or objective manifestations of life, are of a material or physical character, and the purpose of the biologist is to apply to them the principles of physics and chemistry as far as these will carry him, and in many directions they have already carried him far. When however we consider the subjective phenomena of life, or consciousness, the question seems to me a metaphysical one and we are without assurance that physics and chemistry can lead us beyond the boundaries of it. Indeed just where physics and chemistry leave off, I feel a real and deeper problem begins. If so, the question lies at present beyond the reach of natural science which biologist and physicist alike interpret as the science of matter and energy.

In what follows I shall try to review very briefly the principal ideas upon which modern physics rests and shall say something about where we think we have arrived in our search for knowledge. I need scarcely remind you that in the natural sciences as in more practical affairs, *how* we have arrived is as important as *where* we have arrived. I shall therefore spend some time in presenting detached fragments of the experimental evidence and inferences upon which certain conclusions are based, hoping in this way to illustrate some of the constructive methods of reasoning employed in research.

The ideas which underlie all our thinking are space, time and inertia or mass. With space and time as a background, the physicist must pursue inertia and everything related to it, along every conceivable path. In this pursuit

he comes upon four ultimate though related conceptions: Matter, Ether, Electricity and Energy.

The historical development of these conceptions cannot even be sketched in such a lecture as this, but it should be remembered an important part of our present knowledge of matter, and nearly all that we know of the ether and electricity, has been gained not immediately but by inference. In so many cases we see or know directly only the first and last link of a chain of events and must search by indirect means for the mechanism lying between.

At bottom, I suppose, the ether, electricity, force, energy, molecule, atom, electron, are but the symbols of our groping thoughts, created by an inborn necessity of the human mind which strives to make all things reasonable. In thus reasoning from things seen and tangible, to things unseen and intangible, the resources of mathematical analysis are applied to the mental images of the investigator, images often suggested to him by his knowledge of the behavior of material bodies. This process leads first to a working hypothesis, which is then tested in all its conceivable consequences, and any phenomena not already known which it requires for its fulfilment, are sought in the laboratory. By this slow advance a working hypothesis which has satisfied all the demands put upon it gradually becomes a theory which steadily gains in authority as more and more new lines of evidence converge upon it and confirm it.

If we now consider more closely the nature of the conceptions, matter, ether, electricity and energy, we shall later find that matter, ether and electricity possess some attributes in common, and if we take careful heed to what we shall understand by the word, we may call them substances. Energy appears as the measure of their possible interactions.

Taking energy first: All the numberless changes we

see taking place in the universe are, we think, manifestations of the interactions among matter, ether and electricity. With every changing aspect of nature, energy is passing from body to body and undergoing incessant transformations, but its amount is always measurable by the work it may accomplish when harnessed.

Our knowledge of the uncreatable and indestructible character of energy has given us a universal test which we may freely apply to all phenomena to prove our knowledge of them. For when the required energy relations are not satisfied by our explanations, it means we have not got to the bottom of the case, but must strike deeper in to realize the whole of the concealed mechanism.

Charmed by the simplicity and sweep of the law of the conservation of energy, a small school of physicists, who have mostly entered in by the door of physical chemistry, have frankly set energy before inertia and have endeavored to deduce matter and all else from it. This can of course be done, for physics has become a body of thought so closely knit together that all things in it are somehow related. Seen broadly however the new method has few obvious advantages over the historic procedure and not a few evident defects.

Matter has two indisputable hallmarks, two properties in the possession of which all the infinitely varied forms of matter unite, inertia and weight. By inertia we mean that active resistance shown by every piece of matter to any effort to change its motion; while the mutual attraction between all material bodies, according to which all matter strives to collect itself into one huge compact lump, we call gravitation. The gravitational pull of the earth upon a portion of matter is its weight. If we find anything in the world however strange which possesses both inertia and weight, we may call it matter without further examination.

The ether which surrounds and encloses all our universe we came first to know as the bearer of waves of light and heat. Ever since that time we have known it to possess inertia; for no medium devoid of inertia can carry forward a wave motion.

Thus the ether has one of the hallmarks of matter. Has it also weight? This we cannot hope to know until we find some way as yet undiscovered to alter the natural distribution of ether between two portions of space. Here it should be remembered that the weight of gases was first proved after the invention of the air pump and barometer. But alas, how shall we go about building an ether pump when all material walls seem more porous to the ether than the coarsest sieve is to air? And worse, the ether appears to be incompressible. The question of weight is thus at present in abeyance and we leave it.

Of the properties of electricity alone, it is still difficult to speak. The subject is easiest approached from the relations of electricity to ether on the one hand and the relations of electricity to matter on the other. It is in this last and more complicated phase of our subject, that the most brilliant advances have recently been made.

To state the case between electricity and ether, we must begin with Faraday and some of the mental images he formed of the connection between them, which have proved at once the most simple and useful aids to thought to be found in the whole history of physics. Faraday realized as well perhaps as we do to-day that electricity could no more be made outright, than could matter. The utmost which could be done was to separate positive and negative electricity. If therefore, any one exhibited a positive charge, there was somewhere in the universe an equal negative charge, to which it was drawn by invisible means across the intervening space.

Faraday maintained the forces of attraction were due to

some kind of strain in the ether lying between. To picture the more vividly to himself and to others, the character of the stresses in this medium transmitting the force which one charge exerts upon another, he supposed contractile filaments called lines of force to traverse the ether between the charges. To make the case more definite he gave direction to these lines assuming that they originated on the positive charge and terminated on an equal negative charge nearby, or far away, according to circumstances.

The motions of electric charges when free to move, and the distribution of stresses in the ether roundabout, show that all happens as if each line of force were pulling like a stretched elastic thread to shorten itself and draw the charges together, and at the same time unlike any elastic thread we know, it was repelling or pushing sidewise at the other force lines near it.

If a charge of positive electricity be given to a metal sphere, and the negative charge from which it has been separated be dissipated to remote bodies or be carried so far away that its position is no longer of any immediate importance, lines of force will start from the spherical surface of the conductor in all outward directions, and will be precisely radial. As many lines will leave from any one half of the sphere as from another. This equal radial arrangement of the lines of force is produced by the sidewise shoving of each line of force upon its neighbors until the stresses in the ether at the bounding surface of the metal are equal on all sides.

If now the metal sphere with its charge be put in steady motion, it will carry its lines of force along with it, and if the motion be not too swift, all the lines of force will continue radial. But with this motion of the lines of electric force through the ether, a wholly new and additional ethereal force appears—a magnetic force which did not exist when the charge was at rest. This magnetic force is al-

ways at right angles both to the lines of electric force and to the direction of their motion, thus encircling the moving charge. The planes of these circles are perpendicular to the straight path along which the charge is travelling.

As long as the motion and charge remain uniform there will be no change whatever in this magnetic force except that it keeps abreast of the sphere as do the moving lines of electric force on which it depends. As soon as the motion ceases the magnetic force disappears and soon all is as it was before the motion began. But while the sphere is starting or stopping, before it has reached its steady motion or while it is coming to rest, the electric and magnetic forces are undergoing readjustment and this disturbance spreads outward through the ether with a speed precisely equal to the speed of light. Nor is this a chance agreement for we now know that light consists of nothing more than very rapidly and periodically changing electro-magnetic forces travelling out through the ether from a particular source of electric disturbance, called a luminous body. The ethereal phenomena we have noted around a moving charge faithfully repeat themselves about a wire carrying an electric current and it was here that Faraday found them.

To the mental images of Faraday—these lines of force which helped him to grapple with the unseen, to form working hypotheses, to experiment: to these Maxwell applied the powerful resources of mathematical analysis and reared the splendid structure of the electro-magnetic theory. Now that the work is done we may let fall the scaffolding which Faraday's vivid imagination supplied but we could not earlier have done without it. Here we have the whole chain, mental image, hypothesis, experiment, theory.

As we now take up what we believe to be the relations of electricity to matter, we come in places upon slippery

ground and the bases of our faith rest on recent foundations.

At the outset we encounter one striking difference between electricity and matter. Every free charge exerts a force upon every other charge in the universe, just as every particle of matter exerts a force on every other particle of matter however distant. But with matter the particles are invariably urged toward each other while electric charges may be either drawn together or forced apart depending on the kinds of charges. We have both positive and negative electricity but only one kind of matter.

Just how these two kinds of electricity are different we know little beyond the invariable law that positive attracts negative and repels positive. In some ways positive and negative electricity resemble right and left handed things. If the same number of right and left handed turns be given to a screw, one hand will precisely undo the work of the other. If the right and left hands be brought together they fit part for part, but two right gloves are a poor pair. On the contrary there is no right and left to gravitation. Two pieces of matter always fit in the gravitational sense.

The bald statements of the laws of gravitation and electric force bear a strong resemblance to each other. The laws tell us how the forces *vary,* but reveal no hint of the machinery by which they *act.*

Gravitation was the first force man encountered and it is still the one he knows least about for we have got no further than where Newton left it two and a half centuries ago. We have some inkling of the possible machinery by which one electric charge acts upon another at a distance and we feel nearly as sure that the push or pull is carried by the ether as that the pull of a horse on a cart is through the traces which bind him to it. With gravitation the case is very different for we have n't as yet the slightest valid conception of *how* the pull of one mass upon another is

conducted across the intervening space, nor *what* conducts it. We can get no further until the speed with which gravitational disturbances travel has been measured, and no one at present seems to know how to go about making such an experiment.

One further difference between gravitation and electric force. The force of attraction or repulsion between two charges of electricity is diminished by replacing the free ether between them with any material medium, but the force of gravitation between two bodies remains constant as long as the distance remains constant, and intervening masses are powerless to shield or to alter it. Hence we cannot yet attribute the gravitation of matter to any electricity which may be contained in it, nor prove the ether to be the medium through which the force acts.

Gravitation is still unconnected, unattached to anything else in nature; as independent as Mr. Kipling's "cat that walked by himself, and all places were alike to him." It is still the stumbling block to the physicist which it has been these many years. How can he explain a universe when he is unable to give a reasonable account of the cement which holds it together?

Of the intimate association of electricity with matter we have learned much from careful study of the processes of electric conduction in solutions and gases.

When a simple chemical compound, (and it should here be borne in mind that the molecule of a compound is built up of atoms of at least two different kinds)—when a simple chemical compound, hydrochloric acid for example, is dissolved in water and an electric current is passed through the solution, the products hydrogen and chlorine of the decomposed acid appear in definite proportions at the points where the current enters and leaves the liquid—the chlorine where the current enters, the hydrogen where it leaves. We know this current to consist of processions

of single charged atoms, a disorderly march perhaps, with a crowd of bystanders obstructing the way, but the movement is always forward, each constituent of the broken molecule carrying a definite electric charge. These processions are always double. The atomic carriers of the positive charge moving in one direction, those carrying the negative charge in the other. The same quantity of positive electricity is carried by one procession, as negative electricity by the other. We have not only measured the charge carried by a single atom but the average speed with which the atoms traverse the solution. It has been found further that atoms of the different chemical elements having the same mating value, technically called valence, always carry the same unvarying charge whether the atoms themselves be light or heavy. These charged atoms, in some cases atom groups, are spoken of as *ions*.

Such electrolytic experiments as these have led to two surprising results. First: no electric charge smaller than that carried by an atom of the hydrogen valence has yet been found. Second: all other small charges are exact multiples of this value.

We have long been familiar with the idea of atoms of matter but here for the first time we come across something which looks very like an atom, or natural unit, of electricity. The justification for calling it an atom of electricity is like the argument for the atom of matter. Moreover we know some eighty different kinds of material atoms but only two kinds of electric atoms, a positive and a negative. Thus the electric atom of the two has the greater claim to simplicity. When we speak of an electric atom disregarding for the time the matter associated with it, we call it, not an *ion* but an *electron*. Evidence will later be given suggesting ways by which we may wrench a negative electron wholly free from matter, and experiment with it in its detached and pure state.

We are now in a position to consider the rôle electric forces play in holding atoms together within a compound molecule, for, from the foregoing, it appears when a molecule is broken in two, the fragments are always found equally and oppositely charged, and they doubtless held these charges within the molecule. But the distance separating the two parts was then so small that all the lines of force from the positive charge ended at once on the equal negative charge, and no force lines strayed beyond the molecular boundary. Hence no evidence of an electrical charge could be found in the ether outside the molecule. It seems probable therefore that the electric force between the atoms of matter in the molecule supplies the chemist with the cement he has long called *chemical affinity*.

The ratio of the electric charge to the mass of the particle on which it rides (in our processions) has come to be one of the most important quantities in physics. As we know both the quantity of matter and quantity of electricity transferred by a given electric current, we can express this ratio for each chemical element. Hydrogen gives the largest ratio found in solutions.

Systematic study of the conduction of electricity in gases is of more recent origin but the knowledge gained from it not only confirms the ideas formed to explain conduction in solutions, but has very widely extended and simplified them. The chief difference between electric conduction in solutions and conduction in gases arises from the large number of broken molecules or ions always present in solutions. These require only the presence of an electromotive force to start them marching, but a gas, in its natural or non-conducting state, contains very few ions, not enough to support even a very small current, and for this reason gases are insulators.

In gases however there are many ways of making ions, X-rays, radium rays, rays of ultra violet light on metals,

combustion in flames, white hot bodies of every sort will do it. But there is one method which depends on the violent collisions of ions with molecules which is so objective in its form I cannot forbear attempting to describe it. It is also the method which leads us to cathode rays and much more.

Imagine then a glass tube into each end of which a conducting rod carrying a small metal disc is sealed. These rods may at will be connected to the terminals of a battery. If while the tube is filled with a gas, in its non-conducting state, the battery be applied, the very few ions always present are set in motion but the too frequent collisions in the swarm of neutral molecules which obstruct the way prevent the moving ions from attaining more than moderate speeds.

By connecting the tube to an air pump as many as we like of the interfering molecules may be removed. As more and more gas is drawn out of the tube, the moving ions encounter fewer and fewer collisions and in consequence attain higher and higher speeds, as small shot might fall through a gradually dispersing swarm of bees poised in midair. The longer the pumping is kept up the greater the maximum speed of the ions becomes and the more violent are the collisions which do occur. When nearly all of the gas has been drawn out of the tube, a stage is reached where the encounters between flying ion and indifferent molecule become so violent that molecules are shattered and new ions produced, which in their turn work more destruction.

When this stage is reached, the gas is a good conductor, but if the pumping be carried too far, a second stage appears in which the encounters are too few to make enough new ions to support the current, and the gas finally ceases to conduct systematically. It is near the end of the conducting stage that the much discussed cathode rays appear. They depart from the cathode or metal disc in the end of the tube connected to the negative side of the battery.

The extraordinary resourcefulness, shown by the leading workers in this field of recent enquiry, in untangling the complex snarl of phenomena presented, marks a very great achievement. So inspiring from the human side as well as the physical has been this unequal contest of man with nature, of mind struggling against disorder, and so bravely done, that I ask your indulgence while I try for a few minutes, fragmentarily, to describe one or two fundamental experiments.

Cathode rays are invisible but many substances—fortunately glass is of the number—shine with a bright phosphorescent light when placed in the path of the rays. By this means it was early discovered that cathode rays travel in straight lines which always leave the cathode making right angles with the metal surface from which they depart. It is possible therefore to make the cathode concave or saucer shaped and thus bring the rays to a focus at some point in the tube. If cathode rays are thus focussed upon the blades of a very delicate paddle wheel which rotates easily upon an axis, the wheel is set revolving as if struck by a stream of moving matter.

The rays are found to possess an unusual power of penetrating matter impervious to light. They will even traverse a considerable thickness of aluminum. A comparison of the absorbing powers of different materials for cathode rays shows absorption to be roughly proportional to the density of the substance.

There is a field of magnetic force about a beam of these rays and this added to the transfer of electricity along the path gives to the cathode stream the distinguishing marks of an electric current in a wire or a procession of electrically charged bodies. If a magnet be brought near the tube the cathode stream is deflected from its direct course. This deflection by the magnet shows three things: first, cathode rays are not of the nature of light rays, the path of which a magnet is powerless to change. Second, the curved

path which the stream follows again shows the stream to possess inertia. Third, the side to which the rays are deflected indicates a stream of negative electricity.

Strongly electrified bodies brought near the tube also deflect the rays. It is possible to determine the speed and the ratio of charge to the mass of the cathode particle, by measurements of the curvature of the path due to the combined magnetic and electrostatic deflections. Speeds as high as one tenth the velocity of light or 100,000 times the speed of a modern rifle bullet have thus been observed. The ratio of charge to mass comes out nearly a thousand times that found for the hydrogen atom by electrolysis. If the charge on the cathode particle is no larger than that on the hydrogen atom, which was called an atom of electricity, then the inertia or mass of these particles is only one one-thousandth part of the mass of hydrogen atoms.

The nature of cathode rays was thus determined but at this stage it was all important to catch a known number of these missiles and measure the electric charge each carried. As the estimated size of these minute bodies is less than one ten-million-millionths of an inch, direct counting would be both slow and difficult, yet by one of the most ingenious experiments ever performed, Professor J. J. Thomson did it, indirectly.

To bring the essential features of this remarkable experiment before you, I must begin some way off by reminding you of several things you already know. For instance, the quantity of water vapor which a given volume of air at ordinary pressures can hold without depositing it as a mist or rain, increases with the temperature. If air inclosed in a vessel is allowed to expand suddenly its temperature falls. If the air were initially saturated with water vapor, after the expansion some of the vapor will go into mist or rain provided any nuclei are present upon which the excess vapor can condense. In the ordinary fog

or shower the dust particles always present in the open air act as nuclei for the formation of drops. Small free charges of electricity or ions serve the same purpose and the negative ions are more effective condensors than the positive, hence they come down first.

In a complicated vessel which need not be described, Professor Thomson admitted dust free air saturated with water vapor. This mixture was allowed to expand several times to make sure of freeing it from accidental dust or ions which might be present. The former pressure was then restored and the gas ionized by admitting X-rays through the thin aluminum lid of the gas chamber. The next expansion, chosen sufficient in amount to cause condensation on the negative but not on the positive ions, caused a copious cloud of mist which gradually settled by its own weight to the bottom of the vessel. The top of the cloud as it fell was sharply defined, and its rate of descent could be measured.

Sir George Stokes many years before had calculated the rate of fall of small spherical bodies through air and one needed to know only the density of a small sphere and its rate of fall to compute its size. The approximate volume of the individual drops could thus be found. The quantity of water in the whole shower could also be easily determined, hence the number of drops, equal to the number of negative ions upon which they might form, could be calculated.

In another way Professor Thomson could measure the total quantity of free negative electricity present in the chamber when the fog was precipitated. He had thus the number of negative ions and the sum of their charges, and therefore the charge each carried.

The charge Professor Thomson found as the result of his brilliant experiment was the atom of electricity over again. After this it was impossible to escape the conclusion

that the bodies flying in the cathode stream were masses no greater than the one one-thousandth part of the hydrogen atom. Thus matter, or electricity, or something exists, which measured by inertia is a thousand times smaller than the lightest known atom of matter. Furthermore the kind of gas in which the cathode discharge took place had no effect upon either the charge or the mass of the particles, which bear no observable earmarks to reveal the kind of matter out of which they come. Whatever their source they are always the same.

So far as we now know the cathode particle or negative electron is a minute portion of pure negative electricity, wholly free from matter. An atom of electricity, and nothing more. Its small inertia can be wholly explained to be of the kind electric charges borrow from the ether which surrounds them.

When electrons driven at high speeds down the cathode stream are suddenly stopped by striking a target of dense matter like platinum, the point where the target is struck becomes a source of X-rays. We have already seen that a moving electric charge when brought to rest sends out a pulse of electro-magnetic disturbance in the surrounding ether, and the greater the suddenness with which the motion is arrested, the sharper and more abrupt is the shock to the ether.

In one sense the principal difference between X-rays and the yellow light from a sodium flame is analogous to the difference between the air disturbances caused by an irregular jumble of sharp thin reports of small percussion caps, and the droning of a heavy organ pipe. One is a tangle of single shocks, the other a steady wave motion. Thus regarded, nearly all the remarkable properties of X-rays find a reasonable and easy explanation.

Turning now to the positive terminal of the tube: Under suitable conditions of experiment it is possible to get a

stream of particles from it. Named as children are before their natures are in the least understood, these rays were called "canal rays." Like cathode rays they consist of flying missiles, but carry positive instead of negative charges. Compared with cathode rays their speed is very moderate and the ratio of charge to mass is of the same order as that for the lighter atoms in conduction through solutions. This ratio varies somewhat with the kind of gas in the tube. Thus canal rays are probably a stream of material atoms which have lost one or more negative electrons.

All efforts to obtain a charge of positive electricity free from matter—a veritable positive electron—have thus far failed.

The extreme complexity of the material atom is strikingly shown by the light from incandescent gases and vapors. When examined by the spectroscope the single element iron exhibits hundreds of definitely placed bright lines in the visible spectrum alone, which means the iron atom must be capable of vibrating in hundreds of different periods. No single atom need be vibrating in all these ways at the same instant, but if all iron atoms are alike, and we have every reason to believe they are whether shining on earth or in the stars, then every atom of iron must be capable of swinging or bounding, revolving or shuddering, or doing something in all these ways.

Before the evidence of the spectroscope the older idea of the atom as a simple structureless body falls to the ground. The complexity of a grand piano seems simple in comparison with the iron atom. But spectroscopic evidence does not end here but indicates what it is in the atom which does something and how it does it.

Ten years ago Professor Zeeman placed a sodium flame between the poles of a powerful electro-magnet and examined its light by the spectroscope. He observed the most striking and peculiar effects of the magnetic force on the

character of the light. The time is too far gone to permit a description of what the effects were, but the light sent out by the flame showed exactly the characteristics which magnetic force would produce, provided the light came from atoms inside which minute electric charges were rapidly revolving. It was even possible to compute the ratio of charge to mass for these revolving mites. The ratio revealed was that previously obtained for the cathode particle.

Hence the mechanism which enables the material atom to emit light is the same electron we met flying through the vacuum tube, now revolving in an orbit about the atom center as a planet revolves about the sun. Thus the chief difference between the atoms of one chemical element and those of another, may lie in the number and arrangement of electrons in a revolving system.

It had long been known that hints about the internal fabric of the atom would be most effectively sought with the spectroscope, but we have here gained at a single bound the most amazing insight into a most complex system. Here also we meet another of those astonishing previsions of Faraday. He tried Zeeman's experiment over fifty years ago, but was balked in his quest by the inadequacy of the instrumental equipment of his day.

The quite recent discovery of the wholly new and unsuspected property of radio-activity in a group of heavy elements has done much to confirm the views already expressed of the connection between electricity and matter, and much more, for radio-active phenomena suggest for the first time that some kinds of matter are not only unstable, but mutable.

Taking radium as the most highly developed example of its class, we find it, with the help of its numerous progeny, sending out three distinct types of rays which for convenience of classification have been called α, β and γ-rays.

α-rays closely resemble canal rays. They carry positive electric charges and possess a mass or inertia comparable with that of the helium or hydrogen atom.

β-rays appear identical with cathode rays. They consist of negative electrons hurled out at speeds as great as nine-tenths the velocity of light.

γ-rays are of the nature of X-rays—a purely ethereal phenomenon. All these rays penetrate matter to varying depths, and absorption varies with density as in cathode rays.

α, β and γ-rays, all have the power of wrenching electrons free from substances which absorb them. By their power to ionize gases a wholly new method of chemical analysis has sprung up—the method of analysing by the electroscope. So marvelously delicate is this new radio-analysis that one part of radium in one-hundred-million-million parts of uranium cannot escape detection. The electrometer test for differentiating the various radioactive substances is the time required for the fresh product gained by chemical manipulation to lose half its ionizing power. This important characteristic of each substance is disparagingly called its *rate of decay.*

By the aid of the new analysis, Rutherford and others have found that radium is slowly disintegrating into radium emanation, which in turn changes into a distinct substance called radium A, and so on by successive steps down the alphabet to radium F, which is possibly a parent of lead. Helium appears also as a by-product of radium disintegration. From radium downward each of the seven substances has a characteristic rate of decay ranging from 1300 years for radium, to three minutes for radium A. Radium emanation is a gas which liquifies at—150° C. Some of the later products seem to be solids.

Is it not amazing that any of the properties of these six derivative products should be known at all, when never

yet has one of them been seen, nor weighed, nor caught for direct examination?

Not only has radium offspring down to the sixth and seventh generation but it apparently has ancestors as well. It is only a link in a genealogical chain. The probable discovery of radium's immediate parent was published less than a month ago by Boltwood. Uranium is thought a remoter ancestor, possibly a great-grandparent.

Accompanying the atomic disintegration of radio-active substances large quantities of heat are evolved showing vast stores of energy hitherto unknown inside the atom.

The most reasonable explanation yet offered of the observed radio-active phenomena indicates that the complex system of electrons revolving at enormous speeds within the atom gradually loses energy until the configuration becomes unstable. A sudden readjustment takes place—a kind of internal explosion by which electrons or α particles, or both, are hurled out. The atomic structure thus relieved starts life as a new substance with a lower atomic weight. Later the new substance for a like reason again becomes unstable, another explosion occurs, and an atom of yet another substance is born.

If this interpretation of the evidence be accepted a conclusion of vast importance may be drawn. We have, we cannot say going on before our eyes, but we may say in a sense going on under our hands, a slow evolution or transmutation of matter. This conclusion is not accepted as yet without reserve for it strikes too deep at one of the assumptions of our older knowledge. Material atoms have long been thought of as immutably fixed for all time, but so were animal and plant species before Darwin. The growing evidence for this larger view of matter, though recent, is already too strong to be longer ignored. The burden of proof is gradually shifting, and to Alice's question "Why?"

comes back the equally pertinent "Why not?" of the March Hare.

To gather a little together for the closing:—The electron has but a thousandth part of the inertia of the lightest known material atom, and this inertia it doubtless borrows from the kindly ether and does not hold in its own right. Its behavior is that of an atom of negative electricity pure and simple. Its form is spherical and not spheroidal. Its size is probably less than one ten-million-millionth of an inch. When revolving briskly enough in an orbit within the atom it gives us colored light of highest purity. When violently jostling irregularly about it gives us white light, without it all light would be impossible.

We believe we have found electricity free from matter but never yet matter free from electricity. Finally comes the suggestion that matter no less than life may be undergoing a slow but endless evolution.

Some of these things and many others have led physicists to suspect that if all electricity were removed from matter nothing would be left, that the material atom is an electrical structure and nothing more.

There are however many stubborn questions to which answers must somehow be found before the so-called electron theory of matter can be accepted unreservedly. As it stands it is at once a most brilliant and promising hypothesis but has not yet reached the full stature of a theory.

Should it hold good the material atom with its revolving electrons becomes the epitome of the universe. The architecture of the solar system and of the atom, the very great and the very small, reveals the same marvelous plan, the same exquisite workmanship. The conservation of energy becomes an ethereal law and the ether the abiding place of the universal store of energy.

To end as we began, we have matter and electricity which some day may be one, and ether and energy. Of

these we hope sometime to build in theory, a reasonable world to match the one we now so little understand.

When all the interrelations among matter, ether, electricity are separated out and quantitatively expressed, we believe our work will be complete.

Such then is the confession of faith, the very far distant hope of the modern physicist.